SOME OF THE RESULTS OF ASTRONOMICAL PHOTOGRAPHY PERTAINING SPECIALLY TO THE WORK WITH A PORTRAIT LENS.

(Plates I–VI.)

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In the present paper I wish to offer a few specimens of astronomical photographs which have been made with portrait lenses. These pictures, which are from my own work, are fair samples of what can be done with this class of lens. They have been selected to show the variety and extent of the work, which covers the Milky Way, the nebulæ, the larger star clusters, meteors, comets, the earth-lit and the totally eclipsed moon, etc. Most of the pictures were made with the 10-inch Brashear lens of the Bruce telescope of the Yerkes Observatory.

The Advantages of Photography in Astronomy.

Before the application of photography to the study of the heavens, one saw the sky but poorly indeed, and in the light of the revelations of the photographic plate today, one is almost tempted to say that he did not see the heavens at all, so vastly has photography enlightened us as to the actual appearance of the sky and its citizens.

There are two causes that have helped to produce this wonderful power that photography has given us. First, above all, the great sensitiveness of the photographic plate over that of the human eye. Second, the fact that our plates show us a vastly larger space of the heavens than the visual telescope does—in some cases a thousand times greater than is shown by our most powerful telescopes of today. A wide field of view is of the utmost importance in the study of the tails of comets, of the larger nebulæ and of the cloud forms and structure of the Milky Way, for these in general are very large. The field of view of a visual telescope, which is at most but a mere speck of the sky, is entirely too small to take in the whole of such an object. In the case of the Milky Way, the structural details are on such a grand scale that their true forms could not even be guessed at with the ordinary telescope. The importance, therefore, of the large field that the photographic plate gives us is very evident.

But there is one thing which we must take into account. The time element enters strongly into the photographic part. One may look into a telescope and he will see at once, if the conditions are favorable, the faint star or faint nebula he has in the field of view—it is but a moment that the eye takes to fix the image before it. Perhaps some very faint and difficult object may require a little longer, but it is only because a special moment of steadiness is waited for. The photographic telescope with its highly sensitive plate will not catch the object in that same time. It may require an hour or more before it "sees" it. But with the eye there is no cumulative effect; on the contrary, indeed, it soon becomes tired, so that in a sense, the longer you look the less you see, merely from the fatigue of the eye. With the plate there is no fatigue. The longer it looks the more it sees, so, though it may take it an hour to see what the eye readily perceives in a moment, it does not stop at that point but goes on seeing more yet, the longer it looks. In this way it soon registers things that the eye cannot perceive at all with equal optical means, and in many cases it reveals objects—especially among the nebulæ—that the eye may never see in the actual sky. And, what is of immense advantage, it permanently records what it sees, so that the exact appearance of a nebula may be preserved for future reference perhaps hundreds of years hence, while the view obtained by the eye is as evanescent as the fleeting glimpse of the object itself. Even though the observer should make a careful drawing it is too often worthless, and misleading, for reference with other drawings, made later on; for the astronomer is seldom or never an artist.

If one examines drawings of the same celestial object by different observers, he is often struck with the want of agreement in these pictures. There are a few of the more prominent nebulæ such as the celebrated ones of Orion and Andromeda, which have been drawn by many observers. There is a strange want of resemblance among these pictures, and what is worse still there is often but little resemblance to the object itself. There was always the possible excuse that the object had actually changed its appearance in the sky. Photography, however, in the past twenty years has shown that such appreciable changes have not really occurred, though they must occur in the course of time.

The best illustration of this want of harmony in different delineations of the same astronomical subject is shown in the large number of drawings of the solar corona made by numerous observers at the total eclipse of the sun in 1878 which were collected and published by the United States government. No two of the forty odd drawings closely resembled each other and few of them looked at all like the indifferent photographs obtained at the time. Indeed these drawings and other similar ones led an eminent astronomer four years later to declare that the corona was not a real phenomenon belonging to the sun, but that it was partly a diffraction effect and partly in the eye of the observer, so that each observer, as it were, saw a different phenomenon—an idea that no one would think of holding today when photography has long since clearly demonstrated the solar origin of the corona.

The real cause of these various discrepancies lay mainly in the want of artistic skill in the observer, who saw the things all right but was unable to draw them correctly, especially was this so in the case of an eclipse of the sun, where the excitement of the moment was enough to unnerve most observers.

Perhaps the greatest sufferer from this want of pictorial skill was the occasional comet. These bodies are really subject to remarkable and rapid changes and hence a misrepresentation was all the more unfortunate. In the case of the nebulæ one could simply throw out the poor representations as being due to lack of skill. In the case of the comet no one can tell whether the want of agreement in the various drawings was not due to actual changes in the comet itself. Happily today, the lack of artistic skill in the individual plays almost no part in astronomical work. The photographic plate, not only with an accuracy far beyond that of the most skillful artist, but with an eye almost infinitely more sensitive, sees the faintest details of a comet or a nebula and records them with a faithfulness unheard of before.

Today the sensitive plate is not only taking the place of the astronomical draughtsman, but it is also running the most skillful measurer a close race. The facility and ease with which great numbers of star places can be measured on the photographic plate, commend it to the most exacting astronomer.

Photography has materially altered our ideas of the nebular theory. From the views of the nebulæ with telescopes not sufficiently powerful to properly deal with them, and hence with views that were more or less erroneous, a theory was elaborated that appealed to the popular mind with a wonderful fascination. There is much that must be changed in this theory to meet the rigid requirements of modern science and to satisfy the demands of what has been revealed in the forms of the nebulæ by the photographic plate.

It is in dealing with the nebulæ that astronomical photography has attained one of its most remarkable triumphs. These bodies in reality shine with a light that has comparatively little effect on the human eye but to which the photographic plate is singularly sensitive. To our eyes the nebulæ are seen "through a glass darkly," as it were, while to the eye of the sensitive plate they are more or less brilliant objects.

Our old ideas of the dimensions of these vast bodies have also been greatly changed. In the days of purely visual astronomy, the great nebula of Orion, covering as it does some half a degree of the sky, was looked upon as inconceivably great in actual extent in space —yet photography has not only increased its extent very greatly, but it has revealed other nebulæ, unknown to us before, that are hundreds of times vaster than this great nebula of Orion. The Pleiades are in the midst of a mighty system of nebulosity that covers at least one hundred square degrees of the sky, and whose actual extent in space almost defies calculation.

Four or five degrees north of the star Antares, in the Scorpion, is a faint star just fairly visible to the naked eye. This is known as Rho Ophiuchi. If one examines the space about this star with a telescope he sees nothing remarkable except that there are fewer small stars in this region—yet photography shows us that the sky here is covered by an enormous and magnificent nebula which apparently lies in a hole in the sky. From this great vacant region—vacant in the sense of there being few or no stars in it—narrow dark lanes run eastward for many degrees. But the singular thing is that the nebula seems in some way to be responsible for the absence of stars at this point. Whether this is due to the obscuration of the light of the small stars that ought to be here, by the nebula, which would in that case prove it to be nearer to us than the stars, or whether the presence of the nebula has in some way destroyed or dispersed the stars cannot be told.

Perhaps the most extraordinary revelations of photography in astronomy have been in the case of comets. These wonderful objects with their vast trains sweeping through space are singularly subject to disturbances by other celestial bodies. The photographic plate has shown us that the comets utterly transform themselves in a few hours' time, for, though of vast dimensions, they are in reality but flimsy affairs with little or no solidity. In these changes, so faithfully recorded by photography, they sometimes, through the distortions of their trains, reveal the presence of some kind of resisting medium or of some unknown bodies through whose attraction, or by collision with which their tails are twisted, broken or deformed in the most extraordinary manner. This was the case with one of the comets of 1893 where photographs on successive nights show the tail disrupted and broken, undoubtedly by such an encounter. What this really means we have yet to learn. Possibly the comet passed through a dense swarm of meteoric bodies in its flight around the sun. Photographs of another comet showed the tail entirely separated from the head and drifting away in space. From these last pictures it was shown that the particles forming the tail were leaving the comet with a velocity of twenty-nine miles a second.

Importance of the Portrait Lens.

The strangest thing in connection with these statements is that the greater portion of these photographic revelations have been made with instruments that are extremely crude in comparison with the elaborate and expensive telescopes with which our great observatories are equipped today. Indeed in many cases the lenses were not made for the purpose to which they have been put. It was only incidentally that their services came to be of benefit to astronomy. I have often thought of the strange difference in the present use of these lenses and the one for which they were originally made. Though it would be hardly fair to attribute their origin to the purpose of human vanity, it was certainly vanity that had much to do with it, for these large lenses were made purely for the taking of portraits. In the days of the wet plate process the slowness of the sensitive agent used in the plates made it necessary to employ very large lenses so as to collect a greater quantity of light, and thus to shorten the time of the sittings. Their use has therefore not fallen to a lower level but has risen to a much higher one—from the picturing of human vanity in the human face to the picturing of the sublime features of the face of the heavens. Their great light grasping power is no longer needed for the enlightenment of human vanity—not that that evil has in any way become extinct—but from the fact that with the extremely rapid dry plates of today the work can be done with very much smaller and less expensive lenses.

Description of Plates.

Nebulæ and Nebulosities.

For an example of nebular photography with a portrait lens perhaps one of the best specimens is that of Plate I (exposure 4 hours), which shows the "North American Nebula." Though this plate does not represent all that is visible on the original negative, it yet shows how beautiful the nebula is, and how appropriate was Dr. Max Wolf's naming of it. The nebula is not a faint object with a telescope—indeed it was discovered over a hundred years ago by Sir William Herschel. It is not, however, suited for visual observations. With a small telescope one sees only a diffusion of feeble light which has no definite form or limits. It is, nevertheless, excellently and specially adapted for photographic representation because of the peculiarity of its light, which is very rich in photographic qualities. A long exposure, however, is required to show the fainter outlying masses of nebulosity which are clearly shown in the present picture. This photograph was made with the 10-inch Bruce portrait lens of the Yerkes Observatory in the splendid atmosphere of Mount Wilson, California, where the writer had taken it in 1905, through the courtesy of Professor Hale, for the photographing of the Milky Way.

This picture exemplifies in a striking manner a peculiarity which is often found in connection with these large nebulosities and to which I have frequently called attention. That is, the apparently free mixture of stars and nebulosity without any evidence of condensation of the nebulosity about the stars. I don't think this is necessarily a case of accidental projection of the stars and nebulosity, for there are numerous similar cases in the sky. In the present case one can trace out a similarity of configuration of the outlines of the nebula and the massing of the stars, which would strengthen the idea that they are at the same distance from us. This fine object is in the Milky Way a short distance east of Alpha Cygni, which star is shown at the western edge of the plate.

A good example of the fainter and more difficult nebulosities is shown in Plate IV, the nebulous region of Gamma Cygni (exposure 6 hours 30 minutes). These nebulosities are not visible with the telescope because of their exceeding faintness. Their full extent is not shown in the photograph, for they extend considerably beyond the limits of the plate. It will be seen that Gamma Cygni, the star in the middle of the picture, is in a region of diffused nebulous matter which extends over a large area and is gathered in masses of greater brightness at different points, but is in general formless and diffused.

The lower picture of Plate IV is a still finer example of the photographic nebulosities—*i. e.*, nebulosities that are too faint to be seen with the telescope and for the knowledge of which we are dependent on the photographic plate. This is the magnificent region of the great nebula of Rho Ophiuchi (exposure 4 hours 30 minutes). Unfortunately the reproduction is a failure, for much of the nebulosity and the great vacancies connected with it, that are so wonderfully shown in the original, are all but lost in this half-tone.

I think there is no other region in the entire sky so remarkable as this of which Rho Ophiuchi appears to be the center. The great nebula itself, which seems to cover almost this entire region with its extensions, and its association with the extraordinary star vacancy here are very puzzling, and lead one to believe that the apparent paucity of small stars at this point is due in some way to the presence of the nebula. The great dark lane or rift running to the east, extends as far as the region of Theta Ophiuchi and seems to be a part of the system of vacancies that occur to the east and south of Theta.

The great nebula is full of remarkable details. There are a number of principal condensations, that of Rho Ophiuchi being perhaps the most striking. The nebula extends to, and involves the bright naked-eye star Sigma Scorpii in a strong condensation full of details. In several wave-like masses it involves and reaches beyond Antares, one of the brightest stars in the sky. It seems to faintly cover a great part of the sky here, extending so far north, perhaps, as to connect with the remarkable nebula about Nu Scorpii. There are traces of it extending as far south as Tau Scorpii.

Perhaps as remarkable as anything in connection with this nebula is the fact that it is so faint that the eye, armed with the most powerful telescope, cannot see it. Its light seems to be almost entirely photographic, and though too faint to be seen in the telescope it is doubtless very bright to the photographic plate.

At the lower part of this plate, a half inch to the left of the small cluster (M 4), is apparently an ordinary star. This is the bright red star Antares which is the brightest in this region of the sky, but which, from its red color, appears quite small and insignificant on the photograph. A half inch above the cluster is the star Sigma Scorpii which is much less than Antares. Sigma Scorpii is the center of a bright condensation of the nebulosity which in the original is seen to connect with the larger nebulosity (in the middle of the plate) about the star Rho Ophiuchi. The dark lanes running from the nebula east, though strong and conspicuous in the original, are nearly lost in the reproduction.

The first picture in Plate II is a photograph of the region of the double cluster of Perseus (exposure 5 hours 55 minutes), which gives a good idea of the gradual massing of the stars from a region of uniform distribution into two clusters whose stars are brighter than the average of that part of the sky.

Meteors.

The unpredicted appearance of the occasional meteor, the suddenness with which it appears and the rapidity of its flight across the sky, make it impossible to locate its path with exactness by eye observations alone; though observers skilled in this class of work can secure a close approximation to the path. If two such observers are separated by several miles, a fair idea may be obtained of the distance of the meteor and of its actual path through our atmosphere. In general, however, there is always much uncertainty attached to such results. What one really sees is a more or less bright point of light darting suddenly across the sky—the duration of whose flight seldom exceeds one second of time and the image of which vanishes from the brain almost as soon as it is formed. It may well be imagined how difficult is the exact location of the path of this fleeting point among the stars. If the meteor could have left a line of light on the sky along the full extent of its course for a few minutes, then one could locate its position fairly with respect to the stars, and yet this would still have considerable uncertainty attached to it from the fact that at best only an estimate (and no measures) could be made with the naked eye of the position.

In photographing the sky with wide angled lenses it is not an uncommon thing for a meteor to take its flight across the region which is being photographed. In this case when it is bright enough, the meteor actually does leave a permanent path among the stars; for the moving point of light affects the sensitive plate, continuously, marking out thus a "trail" among the star images, which is permanent and whose position can be measured with very great accuracy.

If a second camera, some distance from the first one, is also photographing the same part of the sky the meteor trail will be recorded by both cameras and its displacement on the two plates as photographed from these two points on the earth, can be determined accurately and the distance and path of the meteor will become known. Such an instance occurred at the Yerkes Observatory where the same meteor was photographed with two cameras (by Mr. Frank Sullivan and the writer) separated by 400 feet only. The parallax or displacement of the trail among the stars was clearly shown. Measures of these two plates show that the meteor was about 90 miles above the earth's surface.

In Plates II and III are given specimens of meteor photographs selected from a great number of such plates. The lower photograph, of Plate II (region of M 11, exposure 2 hours 40 minutes), shows the trails of two meteors which were nearly in a straight line, so that, at first thought, one would suppose it was the trail of one meteor which had been interrupted near the middle of its flight. Both meteors were moving toward the south, it is assumed (for they were not seen by the observer), and were undoubtedly Lyrids —having a radiant in the constellation of Lyra.

Plate III (α 17 hours 20 minutes, δ south 15°; exposure 1 hour 34 minutes) shows in the first case the full flight of a meteor which evidently exploded near the end of its path, as indicated by that portion of the train which is of greater brightness. The lower photograph shows a great meteor trail and Brooks comet, IV, 1893 (exposure 2 hours 5 minutes). The bright trail was caused by a very large meteor which was seen by the observer. It was moving toward the southeast and exploded just off the edge of the plate. By one who is regularly photographing the sky with these rapid lenses, meteors are thus frequently caught in their flight.

Comets.

Plate V shows two views of Giacobini's comet (c 1905). The first of these (December 29, exposure 1 hour 38 minutes) is the most interesting because of the peculiar form of the tail of the comet. The edges of the tail are convex and sharply defined, and they taper to a narrow neck where they join the head, which is quite large. The tail was doubtless a hollow cone. There is a narrow hazy strip running from the lower or south edge of the tail near the middle of the plate. In the original this can be traced across the edge of the tail onto the tail itself. On the next night, December

30, all this definiteness of form had disappeared and the tail was very wide and diffused.

The lower plate (exposure 1 hour) is very interesting, but the main features of the tail are lost in the reproduction. Both photographs have suffered greatly in making the half-tones.

The Lunar Surface under Various Kinds of Light.

Plate VI shows two photographs of the moon. The size of the lunar image on photographs with a portrait lens (a half inch in diameter with the 10-inch telescope) is too small to be of any importance in the study of its crater and mountain-scarred surface. Such photographs, ordinarily, are, therefore, not worth the making. But there are conditions under which the moon may be photographed to advantage with these lenses—nor for a study of the craters and mountains, however. The first of these pictures (enlarged) shows the new moon with the slender sunlit crescent embracing the dark or night part, where no direct sunlight reaches the surface, or in other words it is the "old moon in the new moon's arms," which sometimes forms such a beautiful picture in the western sky at the vanishing of twilight when the moon is but a few days old. With the exception of the bright crescent, what we see is the lunar night, but it is a full "moon" night, for the illumination is entirely by sunlight reflected from the surface of the earth onto the night side of the moon. At that time if one were placed on this night part he would have seen the earth shining in the night sky like a great round moon (nearly full) some thirteen times bigger than the moon ever appears to us. The distinctness with which the lunar surface is shown in the photograph (with only 20 seconds' exposure) gives an idea of how brilliant the full earth must be when shining in the lunar night. This picture was made for comparison with the full moon and with the totally eclipsed moon, for the surface is then shown under three different kinds of illumination, *i. e.,* direct sunlight (full moon) reflected sunlight (earth lit moon) and refracted sunlight (totally eclipsed moon) to see if any difference could be detected in the appearance of the surface as affected by these various illuminations. Portrait lenses are specially suited for this purpose.

The second picture of this plate is a photograph of the totally eclipsed moon (exposure 9 minutes) in which the only illumination is due to the sunlight refracted through the earth's atmosphere and bent into the shadow of the earth onto the moon. One of the reasons for making this picture was a hope that if any small body should be attending the moon in its journey around the earth (a small satellite for instance) it might be outside the shadow at the time, and being thus illuminated by the sun, would show on the photograph. The moon itself is ordinarily so bright that it would drown out the light of any faint body that might attend it.

Both the photographs of Plate VI are essentially ruined in the reproduction.

List of Lantern Slides.

This paper, when read, was illustrated by a number of lantern slides of the various photographs. A list of these is given below for completeness. I have arranged the slides in the order of subjects.

I. *The Earth-lit and the Totally Eclipsed Moon.*

Slide 1.—The new moon showing the lunar night, illuminated by the "full earth."

Slide 2.—This is the totally eclipsed moon illuminated only by refracted sunlight coming through the dense atmosphere near the earth's surface.

II. *The Milky Way, Star Clusters and Nebulæ.*

Slide 4.—The great star clouds of Sagittarius, east of the Scorpion.

Slide 5.—The double cluster of Perseus.

Slide 6.—The nebulous region of Gamma Cygni.

Slide 7.—The "North American Nebula" in Cygnus.

Slide 8.—The nebulous region of Rho Ophiuchi.

Slide 9.—The nebulosities of the Pleiades. This shows well the remarkable thread-like strips of nebulosity, especially the one from Electra and the one near and parallel to it. The extent of the nebulosities is greater than usually shown in photographs of the cluster. The original negative shows the exterior nebulosities surrounding the cluster. Exposure 3 hours 40 minutes.

III. *Meteors.*

Slide 10.—This shows two large meteors which followed nearly the same path across the plate.

Slide 11.—This shows the full flight of a large meteor on 1898, June 7.

Slide 12.—These two pictures are of the same meteor, but with two cameras 400 feet apart. The small scale picture was made by Mr. Frank Sullivan with 3.4-inch portrait lens attached to the 40-inch telescope during Professor Frost's spectroscopic observations. The other was made with the 6-inch lens of the Bruce photographic doublet. An inspection of the trail with respect to stars near which the meteor passed shows a decided parallax. The distance of the meteor above the earth's surface, from these two pictures, was about 90 miles.

IV. *Comets.*

Slide 13.—Swift's comet on 1892, April 7, showing a large mass and separate system of tails which were going out from the comet.

Slide 14.—Giacobini's comet, 1905, December 29. The picture shows the remarkable appearance of the tail, which on this date was quite unlike the tail of any other comet.

Slide 15.—Borrelly's comet on 1903, July 24. The second photograph on this slide was made by Mr. R. J. Wallace. The interval between the two pictures is 3 hours. The tail which was separated from the comet, had receded noticeably in three hours. Measures of the plates showed that the particles forming the tail were moving away from the comet at the rate of 29 miles a second. (See *Astrophysical Journal,* October, 1903.)

V. *Vacant Regions and Holes in the Heavens.*

Slide 16.—This is a remarkable region of vacancies in a great nebulous background in the constellation of Taurus. (See *Astrophysical Journal* for 1907, April.)

Slide 18.—Vacant lanes running from the nebulous region of Rho Ophiuchi towards the east.

Slide 19.—Great vacant regions about the star Theta Ophiuchi, (See *Popular Astronomy,* No. 140.)

Yerkes Observatory, 1907.